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ABSTRACT

To extend the analysis of mathematics as the "critical filter" into actual college experience, the influence of high school and college mathematics on choice of majors and progress in the major during college was studied using data from 745 freshmen at Arizona State University. Attention was also directed to an expanded mathematics curricula that was designed to provide students the opportunity to remedy their mathematics deficiencies and to pursue math-based scientific or technical college majors and careers. Comparative data were included on: the level of gender segregation and the racial or ethnic distribution of college majors, the high school academic background of students in different majors, and changes in majors during the four years of study. Majors were grouped into seven discipline clusters, classified on the basis of the level of mathematics required. Structural-equation models for each of the seven discipline clusters showed the relationship of students' precollege mathematics background, mathematics course taking, grades, and progress in college majors. Findings include: 45% of students majoring in scientific/technical majors did not have trigonometry or fourth-year high school mathematics; and the majority of college students made some significant change from intended to actual majors during college. (SW)

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Mathematics as the Critical Filter to College Majors: A Structural Model Analysis

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Almost fourteen years ago, in March 1973, University of California-Berkeley sociologist Lucy Sells (Sells, 1973) presented a brief report that was to have a significant effect on the direction and focus of mathematics education research over the next one and a half decades. In an analysis of the academic backgrounds of Berkeley freshmen, Sells found that only 8% of women applicants, compared to the sizable 57% of male applicants, had the 3 1/2 to 4 years of high school mathematics preparation prerequisite to entry-level college calculus. Because calculus was, and still is, a basic requirement of most scientific/technical college majors, Sells concluded that deficiencies in high school mathematics preparation act as the "critical filter" barring the vast majority of women from entry into scientific/technical college majors and subsequent careers.

In a 1976 update of the study (Sells, 1976), Sells reported further that the effects of high school mathematics deficiencies are even more damaging for Blacks. Sells noted that for Black applicants to UC-Berkeley deficiencies in high school mathematics preparation acted as the critical filter to not only scientific/technical majors but to admission to the university itself.

Since its first statement by Sells in 1973 (Sells, 1973), what has become known as the "critical filter theory" has had strong influence on the field of mathematics education research, focusing inquiry almost entirely on precollege mathematics and factors related to the low mathematics achievement and participation of women and racial/ethnic

minority students at the precollege level. Researchers have found that the generally lower high school mathematics participation and achievement of women and/or racial/ethnic minority students are the products of complex webs of cognitive, affective, behavioral, and background variables (Olstad, Juarez, and Haury, 1981; Parsons et al., 1983), causal attribution (Covington and Omelich, 1976), parents' education (Gemmill, Monteil, and Bustoz, 1982), and language (Cuevas, 1984). Researchers have found these factors act either singly or in combination to deter particularly women and racial/ethnic minority students from enrolling in elective high school mathematics courses.

However, there is a small body of recent research that finds few gender differences in high school mathematics participation rates. Results of the Women in Mathematics study sponsored by the Education Commission of the States (Armstrong, 1980) revealed few gender differences in participation in lower-level high school mathematics, including General Math and Algebra I. However, the study did confirm a small but still significant difference in participation in trigonometry, calculus, and precalculus. Another assessment by National Assessment of Educational Progress (Wise, 1978) also found gender differences in precollege mathematics only at the level of trigonometry, precalculus, and calculus. Results of studies such as these suggest that, if critical filtering occurs at all, it is within the narrow time span usually associated with 4th-year high school mathematics.

Further, to date, the body of research on mathematics and students has a number of significant gaps. Researchers interested in the impact of factors influencing mathematics participation and achievement generally

have not looked beyond high school to the possible interaction between mathematics and students' actual progress in college majors and careers.

Part of the reason for the concentration of research on precollege mathematics is found in the critical filter theory itself. While the critical filter theory identifies mathematics as the key to entry into scientific/technical college majors, it also says that the decision of who may pursue these majors is made before college. This conclusion was reiterated recently in the influential Rockefeller Foundation-sponsored study, Who Will Do Science? which concluded that "by the conclusion of high school only those already in the scientific/technical game have the option of continuing to play it (Berryman, 1983, p. 12).

However, many conclusions such as this regarding the impact of precollege mathematics participation and achievement on choice of college majors were based on students' intended, not actual, college majors. Yet, results of studies on students' choice of majors in college (e.g., Davis, 1965; Astin & Panos, 1969; Theophilides, Terenzini, & Lorang, 1984) indicate that the majority of students change majors during their college careers. Further, a number of curriculum changes have occurred on most campuses over the past decade that may have altered the role mathematics plays in major and career choice. For example, many majors which were previously not math-based such as criminal justice, communications, the social sciences, and business administration, have added college mathematics requirements in response to the technological revolution and the infusion of computers and statistics into these fields. In addition, college mathematics curriculae at most colleges and universities have changed dramatically, expanding downward to include a wide range of

precalculus courses providing opportunities for college students to recoup their deficiencies in mathematics preparation.

Curriculum changes such as these, together with the findings of research on students' choices of majors during college, all suggest that the critical filter theory may be too narrow in its focus on only precollege math. Instead, a significant interaction between mathematics and students' choices of major during college may be occurring, either negating or substantially modifying the concept of mathematics as the critical filter to scientific/technical careers.

Purpose

The purpose of this study was to extend the analysis of mathematics as the critical filter into the actual college experience. The study addressed the central question: To what extent does mathematics, both high school and college, influence students' choices of majors and progress in their majors during college? In addition, the study assessed whether or not the expanded precalculus curriculum offers underprepared students a legitimate second chance to recoup deficiencies and pursue math-based scientific/technical college majors and, subsequently, careers.

Description of the Study

The study addressed the issue of the effects of mathematics on college major choice through both descriptive analysis and the development of structural-equation models.

Descriptive analysis provided comparative data on the level of gender segregation and racial/ethnic distribution of college majors, the high

school academic background of students in different majors, and the magnitude and direction of changes in majors during the four years of the study. Majors were grouped into seven discipline clusters, classified on the basis of the level of mathematics required (see Table 1).

Structural-equation models for each of the seven discipline clusters were constructed and tested depicting the relationship of students' precollege mathematics background, college academic experience, and progress in college majors. Further, to test the effects of exposure to the critical 4th-year of high school mathematics on students' progress in college, the models were separately estimated for those students with 4th-year high school mathematics and those without 4th-year high school mathematics within each of the seven discipline clusters.

Subjects

The study utilized data for 745 new freshmen enrolled at Arizona State University Fall Semester, 1981.

Data were gathered from several record-keeping systems at Arizona State University. High school mathematics participation and grades were taken directly from students' final high school transcripts. Grades were converted to a standard 4.0 scale.

It is important to note here two points about the curriculum at Arizona State University. First, the university has no institution-wide mathematics requirements. All mathematics requirements are specific to the major. Secondly, in 1981, there were no mathematics placement tests. Students enrolled in a particular level of mathematics on the basis of either advisement or their own perception of their mathematics abilities.

Table 1

College Majors and Mathematics Requirements

Math-Level Group	Initial Groupings
Level 2 - no math requirement	English, foreign languages, social sciences, humanities, fine arts
Level 3 - Intermediate Algebra & Theory of Arithmetic	elementary/special education, nursing, communications
Level 4 - College Algebra & Trigonometry	psychology, premed
Level 5 - Mathematics for Social, Management & Life Sciences	management, finance, business administration, wildlife biology
Level 6 - Mathematical Analysis	accounting, quantitative analysis
Level 7 - Technical Calculus	technology
Level 8 - Calculus	engineering, computer science, physical science

Failure and withdrawal rates in precalculus and calculus mathematics courses at Arizona State University were, and continue to be, high. Approximately 44% of students in mathematics courses in 1981 received grades of either "E" (failure) or "W" (withdrawal). Inclusion of withdrawals into consideration of progress is important because, for students enrolled in either a required course or a mathematics course prerequisite to a required course, withdrawal means a failure to successfully complete mathematics requirements and a possible setback or barrier to progress in their majors.

The study was longitudinal and tracked all mathematics course taking, grades, and changes in majors over a period of four years, Fall 1981 to Spring 1985.

Table 2 presents information on the demographic composition of the study group. Table 3 presents the distribution of the study groups among the seven math-level discipline clusters.

Results

Gender

As Table 4 shows, the math-level discipline clusters demonstrated patterns of gender segregation among academic discipline fields similar to those reported in earlier literature on choice and change of majors (Davis, 1965; Astin & Panos, 1969). Education and the social sciences were female dominated; engineering, computer science, and the physical sciences and technology were male dominated. However, the relatively low level of gender segregation of the study group in business fields is in striking contrast to earlier studies (Davis, 1965).

Table 2

Demographics of Math-Level Initial Major Groups

Major Group	N	Percent Racial/Ethnic Minority	Gender	
			% Male	% Female
2	130	10.8%	36.2%	63.8%
3	72	4.2%	12.5%	87.5%
4	62	8.1%	40.3%	59.7%
5	185	4.3%	54.1%	45.9%
6	73	13.7%	54.8%	45.2%
7	52	5.8%	84.6%	15.4%
8	171	12.9%	81.3%	18.7%

Table 3

College Majors and Mathematics Requirements

Math-Level Group	Initial Groupings	% Students Initial Choice
Level 2 - no math requirement	English, foreign languages, social sciences, humanities, fine arts	17.4
Level 3 - Intermediate Algebra & Theory of Arithmetic	elementary/special education, nursing, communications	9.7
Level 4 - College Algebra & Trigonometry	psychology, premed	8.3
Level 5 - Mathematics for Social, Management & Life Sciences	management, finance, business administration, wildlife biology	24.8
Level 6 - Mathematical Analysis	accounting, quantitative analysis	9.8
Level 7 - Technical Calculus	technology	7.0
Level 8 - Calculus	engineering, computer science, physical science	22.9

Table 4

Demographics of Math-Level Initial Major Groups

Major Group	Gender	
	% Male	% Female
Level 2 - English foreign languages, social sciences, humanities, fine arts	36.2%	63.8%
Level 3 - elementary/ education, nursing, communications	12.5%	87.5%
Level 4 - psychology, premed	40.3%	59.7%
Level 5 - management, finance, business administration, wildlife, biology	54.1%	45.9%
Level 6 - accounting, quantitative analysis	54.8%	45.2%
Level 7 - technology	84.6%	15.4%
Level 8 - engineering, computer science, physical science	81.3%	18.7%

Racial/Ethnic

In contrast to the findings of studies on high school minority students' intended college majors (e.g., Anick, Carpenter, & Smith, 1981; Berryman, 1983), this study showed that racial/ethnic minority students (Black, Hispanic, or Native American) were not segregated in initial majors requiring lower levels or no college mathematics. In fact, as Table 5 indicates, representation of racial/ethnic minority students in two discipline clusters requiring high levels of college mathematics (Level 8 - 12.9% and Level 6 - 13.7%) was above that of the study group as a whole (8.8%).

High School Mathematics Background

Level 2 majors, such as English and fine arts, required no college mathematics competency (see Table 6). Not surprisingly, students in these majors entered college with less high school mathematics exposure, lower mathematics CGPA, and lower ACT mathematics scores than students in the math-based scientific/technical majors. Only 18.5% of the students in Level 2 majors had exposure to 4th-year high school mathematics, compared to an average of 31.9% for all students in the study.

Students in Level 3 initial majors, such as education and nursing, had the lowest high school mathematics CGPA and mathematics exposure rates of students in the study. In addition, the mean ACT mathematics score for this group (17.46) was substantially below that of students in all of the other initial major groups.

Level 4 majors, such as premed and psychology, required college algebra. Students in this group had the highest mean high school CGPA of

Table 5

Demographics of Math-Level Initial Major Groups

Major Group	Percent Racial/Ethnic Minority
Level 2 - English, foreign languages, social sciences, humanities, fine arts	10.8%
Level 3 - elementary/ special education, nursing, communications	4.2%
Level 4 - psychology, premed	8.1%
Level 5 - management, finance, business administration, wildlife, biology	4.3%
Level 6 - accounting, quantitative analysis	13.7%
Level 7 - technology	5.8%
Level 8 - engineering, computer science, physical science	12.9%

Table 6

High School Academic Background

Major Group	Mean High School CGPA (4.0 - 0.0)	Mean High School Math CGPA (4.0 - 0.0)	%ALGI	%ALGII	%GEOM	%TRIG	%ANALYSIS	%CALC	% With 4th Year Math	ACT Math Score (Scale: 1-36) Mean	S.D.
2	3.11	2.61	94.6	66.9	88.5	15.4	5.4	4.6	18.5	19.62	6.42
3	3.10	2.53	94.4	65.3	87.5	12.5	8.3	0	16.7	17.46	5.93
4	3.26	2.83	93.5	77.4	87.1	21.0	8.1	4.8	27.4	20.19	6.48
5	3.12	2.69	91.4	67.0	88.1	17.3	7.6	4.3	23.8	20.38	6.28
6	3.09	2.68	84.9	72.6	94.5	21.9	13.7	12.3	37.0	20.89	6.05
7	3.08	2.59	100.0	80.8	96.2	36.5	5.8	1.9	38.5	23.52	5.63
8	3.24	3.05	96.5	88.3	91.8	32.7	18.7	22.2	55.0	24.67	5.98
ALL	3.15	2.75	93.6	74.1	90.1	22.1	10.3	8.7	31.9	21.20	6.54

all of the discipline cluster groups. However, the mathematics exposure rate and ACT mathematics scores of students in these majors were much lower than those of students in majors requiring higher levels of college mathematics. Only 27.4% had exposure to 4th-year high school math and only 77% had Algebra II, or third-year high school mathematics.

Level 5 majors, such as general business and management, required Mathematics for the Social, Management, and Life Sciences. Level 6 business majors in accounting and quantitative business analysis required a higher level course, Mathematical Analysis, including matrix algebra. While the mean high school CGPA and high school mathematics CGPA of both groups were similar, the two groups differed in high school mathematics exposure rates, particularly 4th-year mathematics. While only 23.8% of Level 5 students had 4th-year high school mathematics exposure, 37.0% of Level 6 students had some 4th-year mathematics.

Levels 7 and 8 comprised the majors typically referred to as "scientific/technical." Level 7 students were all in technology majors requiring Technical Calculus. Level 8 majors, such as engineering, computer science, and the physical sciences, required the more theoretical college calculus.

Level 8 and Level 7 students, respectively, had the highest mean ACT mathematics scores (24.67--Level 8; 23.52--Level 7) of all the disciplines. In addition, Level 8 students had the highest mean high school mathematics CGPA of all seven major groups.

Perhaps the most striking feature of the entire seven group distribution on high school academic background was the percentage of students entering scientific/technical majors without 4th-year high school

mathematics exposure. A substantial 45.0% of the students in these majors did not have the trigonometry or 4th-year high school mathematics the critical filter theory maintains they must have to enter these majors in college.

Changes in Majors

The most dramatic change of major was dropout; 47.9% of the study group dropped out before graduating and were not reenrolled during the Spring Semester, 1985. The great majority (70.2%) of the remaining persisting students made no change from their initial major cluster.

Not surprisingly, the most stable majors were those requiring no mathematics. However, the second most stable were the engineering, computer science, and physical science majors requiring the highest level.

One important end product of this dropout, migration and stability of majors was a resulting gender distribution among final majors substantially different from initial majors. The most dramatic change was decline in the representation of women in accounting and quantitative business analysis, dropping from 45.2% of the initial majors to 23.0% of the final majors (Table 7).

How this dropout, stability and migration among majors was affected by students' high school mathematics exposure and achievement and their college academic progress is described in the following causal models.

Table 7

Dropout and Stability Rates by Math-Level Major Groups

Major Group	% Dropout	% Stability
2	43.1	40.0
3	47.2	37.5
4	51.6	37.1
5	50.8	33.5
6	37.0	32.9
7	61.5	23.1
8	48.0	39.8
All	47.9	36.0

The Structural Model

Diagrams of structural-equation models provide visual conceptualization of the theorized structure as well as the relationship of individual variables. The general initial model tested for all discipline cluster groups is presented in Figure 1. Single-headed arrows represent hypothesized nonzero causal effects from one variable to the variable influenced. Causal effects are either direct or indirect through another variable. Double-headed arrows represent correlations between two variables, such as, college mathematics experience and the non-mathematics experience.

The model has three temporal dimensions. The first is the precollege dimension. This includes five exogenous variables: (a) mathematics exposure, (b) high school mathematics cumulative GPA, (c) high school CGPA, (d) gender, and (e) racial/ethnic minority status. Also included is one endogenous variable, ACT mathematics score.

The second dimension, college experience, contains two endogenous theoretical variables I termed (a) college mathematics experience and (b) non-mathematics academic experience. These were postulated to be predicted directly by each of the six precollege variables and, indirectly, through ACT math scores.

The third, or final outcome, dimension was shift to final major. In the initial model, shift to final major was considered to be the direct effect of each of the individual variables. In addition, the initial model considered shift to final major to be a function of a number of indirect effects.

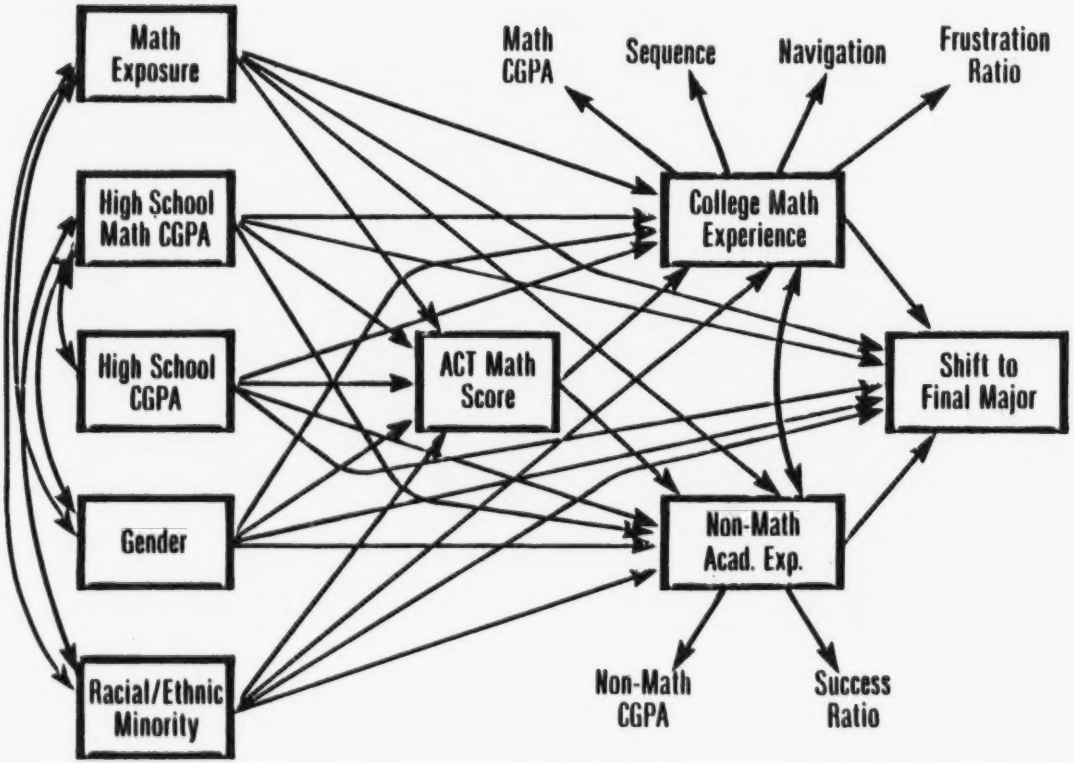

Figure 1. initial model

In the process of refinement of the models, each model was modified systematically with the overall objective of improving the fit while eliminating direct paths from precollege background variables to the final outcome, shift to final major. The modification process improved each of the models, with one exception: the direct path between gender and shift to final major for Level 5 business majors was found to contribute to the fit of the model and thus was retained.

College mathematics experience was expected to have the strongest influence of any variable on shift to final major. High school mathematics exposure and mathematics GPA were expected to have the strongest effect of the six precollege variables on college mathematics experience. Further, the critical filter effects of high school mathematics exposure were expected to result in clear differences in the structure of the models for those students with 4th-year high school mathematics and those without this exposure within each of the seven clusters.

Results demonstrated that there are great differences in the factors and their interrelationships affecting the college academic experiences and changes of majors of students in different major clusters. Final models varied both among the seven math-level discipline clusters and between each mathematics exposure subgroup within each cluster.

College mathematics experience had a significant effect on shift to final majors in five of the twelve models.

High school mathematics exposure, on the other hand, was found to significantly effect the college mathematics experience of only one subgroup. Rather than exposure to high school mathematics, it was high

school mathematics grades that more often significantly predicted students' college mathematics experiences. The most consistently significant precollege variable was high school CGPA, positively predicting the non-mathematics academic experience in nine models and the college mathematics experience in three models.

Gender was a significant predictor of college academic experience for only two of the twelve subgroups, both in business majors. Women in these subgroups tended to have better non-mathematics academic experiences than their male counterparts. However, gender was not a significant predictor of the college mathematics experience.

Conclusion

In summary, let me review the findings of the study and draw some general conclusions.

First, the model developed in this study was successful in explaining anywhere from 8% to 42% of the variance in dropout and changes of majors for students in different major cluster groups. The model provides a good initial base through which researchers can further explore the interaction between college students and mathematics.

Second, the study confirmed earlier findings by other researchers (Davis, 1965; Astin & Panos, 1969; Theophilides, Terenzini, and Lorang, 1984) that the majority of college students make some significant change from intended to actual majors during their college careers. Sixty-three percent of the students in this study changed major clusters. However, 75% of this movement was dropout.

Third, this study and its results indicate that there is an important interaction between students and their college academic experiences, and this interaction impacts choices of majors and careers, as well as dropout.

Further, choice of major/career is not predetermined by a student's decision in high school to take or not take 4th-year high school mathematics. Differences in the fit of the models for mathematics exposure subgroups indicated that 4th-year high school mathematics exposure did affect students' actual college experiences and final choice of major. However, the patterns of these effects were different from those indicated by other research in the critical filter theory tradition. Instead of acting as a single irrevocable event barring access to scientific/technical college majors, 4th-year high school mathematics exposure appears to operate as an artifact reflecting the patterns of both precollege and college academic experiences of students. Students without 4th-year high school mathematics were generally poorer students with weaker high school academic backgrounds. For these students, the non-mathematics academic experience in college was a critical factor in their stability or change of majors. Further, students who entered college without 4th-year high school math dropped out of college at rates ran from 7% to 14% greater than their major group counterparts who had 4th-year high school mathematics backgrounds.

Finally, results of this study do indicate that the expanded mathematics curriculae provide students entering college with mathematics deficiencies the opportunity to recoup their losses and reenter the scientific/technical talent pool. For example, in the major grouping that

included engineering and the physical sciences, one-third of the students who persisted in these majors over four years were students who had entered college without 4th-year mathematics and enrolled in lower-level mathematics courses before calculus.

What these findings say is that, while the critical filter theory has some utility in focusing attention on the interaction between mathematics and college majors/careers choice, the concept is outdated and in need of substantial modification. This study indicates that the interaction between mathematics and students' majors and career choices is complex, continuing beyond high school well into the college experience.

Finally, results of this study indicate that the expanded mathematics curriculae do provide students with mathematics deficiencies the opportunity to recoup their losses and reenter the scientific/technical talent pool.

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